

HUMAN ERROR AND GENERAL AVIATION ACCIDENTS: A COMPREHENSIVE, FINE-GRAINED ANALYSIS USING HFACS

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The Human Factors Analysis and Classification System (HFACS) is a theoretically based tool for investigating and analyzing human error associated with accidents and incidents. Previous research performed at both the University of Illinois and the Civil Aerospace Medical Institute (CAMI) have been highly successful and have shown that HFACS can be reliably used to analyze the underlying human causes of both commercial and general aviation (GA) accidents. These analyses have identified general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents. The next step is to identify the exact nature of these human errors. The purpose of this research effort was to address these questions by performing a fine-grained HFACS analysis of the individual human causal factors associated with GA accidents to assist in the generation of intervention programs.

INTRODUCTION

Ultimately, most aviation accidents do not happen in isolation, rather, they are the result of a chain of events often culminating with the unsafe acts of aircrew. From Heinrich's (Heinrich, Peterson, & Roos, 1931) axioms of industrial safety, to Reason's (1990) "Swiss cheese" model of human error, a sequential theory of accident causation has been consistently embraced by most in the field of human error (Wiegmann & Shappell, 2001c). Reason's (1990) description of active and latent failures within the context of his "Swiss cheese" model of human error has been particularly useful in this regard.

Within his model, Reason describes four levels of human failure, each one influencing the next. According to Reason, *organizational influences* often lead to instances of *unsafe supervision*, which in turn lead to *preconditions for unsafe acts* and ultimately the *unsafe acts of operators*. It is at this latter level, the unsafe acts of operators, that most accident investigations focus.

Unfortunately, while Reason's work forever changed the way aviation and other accident investigators view human error; it was largely theoretical and did not provide the level of detail necessary to apply it in the real world. It wasn't until Shappell and Wiegmann, (2000, 2001) developed a comprehensive human error framework - the Human Factors Analysis and Classification System (HFACS) - that Reason's ideas were integrated into the applied setting.

HFACS

The entire HFACS framework includes a total of 19 causal categories within Reason's (1990) four levels of human failure. While in many ways, all of the causal categories are equally important; particularly germane to any examination of GA accident data are the unsafe acts of aircrew. For that reason, we have elected to restrict this analysis to only those causal categories associated with the unsafe acts of GA aircrew. A complete description of the HFACS causal

categories is therefore beyond the scope of this report and can be found elsewhere (Wiegmann & Shappell, 2003).

Unsafe Acts of Operators

In general, the unsafe acts of operators (in the case of aviation, the aircrew) can be loosely classified as either errors or violations (Reason, 1990). Errors represent the mental or physical activities of individuals that fail to achieve their intended outcome. Not surprising, given the fact that human beings by their very nature make errors, these unsafe acts dominate most accident databases. Violations on the other hand, are much less common and refer to the willful disregard for the rules and regulations that govern the safety of flight.

Within HFACS, the category of errors was expanded to include three basic error types (decision, skill-based, and perceptual errors). In general, decision errors represent conscious decisions/choices made by an individual that are carried out as intended, but prove inadequate for the situation at hand. In contrast, skill-based behavior within the context of aviation is best described as "stick-and-rudder" or other basic flight skills that occur without significant conscious thought. As a result, these skill-based actions are particularly vulnerable to failures of attention and/or memory as well as simple technique failures. Finally, perceptual errors occur when sensory input is degraded or "unusual," as is often the case when flying at night, in the weather, or in other visually impoverished conditions.

While errors occur when aircrews are behaving within the rules and regulations implemented by an organization, violations represent the willful disregard for the rules and regulations that govern safe flight. As with errors, there are many ways to distinguish between types of violations. However, two distinct forms are commonly referred to, based upon their etiology. The first, routine violations, tend to be habitual by nature and are often tolerated by the governing authority. The second type, exceptional violations, appear as isolated departures from authority not necessarily

characteristic of an individual's behavior nor condoned by management.

PURPOSE

The HFACS framework was originally developed for the U.S. Navy and Marine Corps as an accident investigation and data analysis tool (Shappell & Wiegmann, 2000; 2001; Wiegmann & Shappell, 2003). Since its development however, other organizations such as the FAA have explored the use of HFACS as a complement to preexisting systems within civil aviation in an attempt to capitalize on gains realized by the military. These initial attempts, performed at both the University of Illinois and the Civil Aerospace Medical Institute (CAMI) have been highly successful and have shown that HFACS can be reliably and effectively used to analyze the underlying human causes of both commercial and general aviation accidents (Wiegmann & Shappell, 2003). Furthermore, these analyses have helped identify general trends in the types of human factors issues and aircrew errors that have contributed to civil aviation accidents (Shappell & Wiegmann, 2003; Wiegmann & Shappell, 2001a; 2001b).

The FAA's General Aviation & Commercial Division (AFS-800) within the Flight Standards Service and the Small Airplane Directorate (ACE-100) have acknowledged the added value and insights gleaned from these HFACS analyses. Likewise, HFACS was cited by the Aeronautical Decision Making (ADM) Joint Safety Analysis Team (JSAT) and the General Aviation Data Improvement Team (GADIT) as particularly useful in identifying the human error component of aviation accidents.

To date, however, the analyses using HFACS have generally been performed at a global level, leaving several questions unanswered concerning the underlying nature and prevalence of different error types. As a result, AFS-800, ACE-100, the ADM JSAT, and the GADIT have directly requested that additional analyses be conducted to answer specific questions about the exact nature of the human errors identified, particularly within the context of GA.

Previous Findings

For a complete accounting of this work, please see the FY02 and FY03 Annual Reports. In sum however, previous research performed at the University of Illinois and CAMI over the past two years has revealed that roughly 80% of GA accidents are associated with skill-based errors, followed by decision errors (roughly 30%), violations (16%), and perceptual errors (5%; Figure 1). Equally important, the trends for the unsafe acts across the years have not changed.

Moreover, upon examination of the fatal and non-fatal aircrew error data during the years of this study, the only difference between the human error categories was for violations. That is, fatal accidents were four times more likely to be associated with a violation than non-fatal accidents.

The pattern of results was similar when the data were examined for the "initiating" or seminal event in the accident

chain.¹ Indeed, nearly 61% (n = 8,838) of all accidents began with a skill-based error. In contrast, roughly 19% (n = 2,729) of the accidents examined began with a decision error, 8% (n = 1,180) began with a violation and only 4% (n = 564) began with a perceptual error. The remaining 8% (n = 1,125) were associated with a seminal event other than an unsafe act (e.g., a precondition for an unsafe act, such as an adverse physiological state).

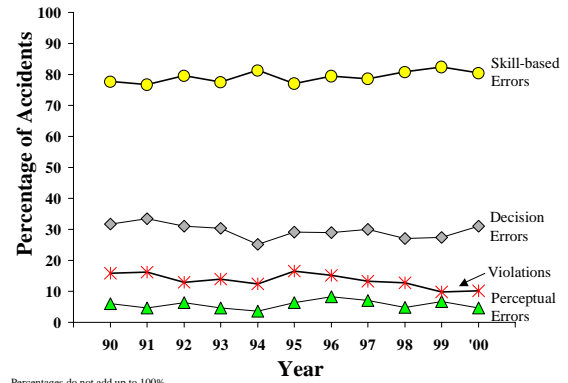


Figure 1. Percentage of accidents by error category by year.

When comparing fatal versus non-fatal seminal errors, what differences did occur (i.e., skill-based and violations) remained relatively constant across the years of this study. Furthermore, the differences were in opposite directions with a higher percentage of fatal than non-fatal accidents associated with violations and a higher percentage of non-fatal than fatal accidents associated with skill-based errors.

FY04 Research Effort

The current research effort focused on the following questions that had also been posed by AFS-800, ACE-100, the ADM JSAT, and GADIT.

Question 1: What are the exact types of errors committed within each error category?

Question 2: Do the types of errors committed within each error category differ across accident severity?

Question 3: Do the types of errors committed within each error category differ between seminal vs. non-seminal unsafe acts?

METHOD

Data

General aviation accident data from calendar years 1990-2000 was obtained from databases maintained by the National Transportation Safety Board (NTSB) and the FAA's National Aviation Safety Data Analysis Center (NASDAC). For analysis purposes, we selected only those accident reports that were classified "final" at the time this report was written, since

¹ Note that unlike the previous analysis where the percentages will add up to more than 100% because there is typically more than one cause factor per accident, these percentages will add up to 100%, since there can only be one "seminal" human causal factor.

only those reports contain the causal factors associated with the accident.

We further eliminated those accidents that were classified as having “undetermined causes,” and those attributed to sabotage, suicide, or criminal activity (e.g., stolen aircraft). When the data were parsed in this manner, we were left with only those GA “accidents” for which causal factors had been “determined” and released by the NTSB.

The data were then culled further to include only those accidents that involved powered GA aircraft (i.e., airplanes, helicopters, and gyrocopters). Finally, since we were interested only in aircrew error, we excluded accidents in which no aircrew-related unsafe act was considered causal or contributory to the accident. In the end, 14,436 accidents involving over 25,000 aircrew causal factors were included and submitted to further analyses using the HFACS framework.

Causal Factor Classification using HFACS

Seven GA pilots were recruited from the Oklahoma City area as subject matter experts (SMEs). All were certified flight instructors with a minimum of 1,000 flight hours in GA aircraft at the time they were recruited. Each pilot was provided roughly 16 hours of training on the HFACS framework. After training, the SMEs were randomly assigned accidents so at least two separate pilot-raters analyzed each accident independently.

Using narrative and tabular data obtained from both the NTSB and the FAA NASDAC, the SMEs were instructed to classify each human causal factor identified by the NTSB using the HFACS framework. After the pilot-raters made their initial classifications of the human causal factors (i.e., skill-based error, decision-error, etc.), the two independent ratings were compared. Where disagreements existed, the corresponding SMEs were instructed to reconcile their differences and the consensus classification was included in the database for further analysis. Overall, pilot-raters agreed on the classification of causal factors within the HFACS framework more than 85% of the time.

Human Factors Quality Assurance

General aviation pilots are not SMEs in the domains of psychology or human factors, and therefore, they may not fully understand the theoretical underpinnings associated with the various error types within the HFACS framework. Hence, pilots might classify human error data somewhat differently than SMEs in human factors. Still, pilots in this study were trained on HFACS, which did give them some level of expertise when assessing human error.

Nonetheless, to be sure that the SMEs had grasped the psychological aspects underlying human error and HFACS, three additional SMEs with expertise in human factors/aviation psychology examined each HFACS classification that the pilot SMEs had assigned to a given human cause factor. Essentially, the human factors SMEs were ensuring that the pilots understood the error analysis

process and did not code causal factors like spatial disorientation as a decision error, or exhibit any other misunderstandings of the HFACS model. To aid in the process, descriptive statistics were used to identify outliers in the data, after which the corresponding NTSB report was obtained. The reports were then independently reviewed by a minimum of two human factors (HF) SMEs for agreement with the previous codes. After the HF SMEs came to a consensus, the codes were either changed in the database or left as the pilot SMEs originally coded them. In the end, less than 4% of all causal factors were modified during the human factors quality assurance process.

RESULTS

Just knowing that skill-based errors (or any other type of error) are a major concern does not provide safety professionals sufficient detail to do anything about it. What was needed was a fine-grained analysis of the specific types of errors within each HFACS causal category, so that targeted interventions can be developed. With this in mind, we compared each HFACS classification with the NTSB’s causal factor designation.

To aid in the presentation of the data, we will examine the fine-grained analysis for each type of unsafe act separately. Included in the results will be the “**top 5**” human causal factors overall, across accident severity, and seminal events.

Skill-based errors. The most frequently occurring human error categories within skill-based errors are presented in Table 1. As can be seen, nearly 12% of all skill-based errors involved errors in maintaining direction control, followed by airspeed (10.63%), stall/spin (7.77%), aircraft control (7.62%) and errors associated with compensating for wind conditions (6.18%). Together, these five cause factors accounted for nearly one half of all the skill-based errors in the database. Additionally, the types and frequencies of skill-based errors coded as fatal/non fatal and seminal events are also shown in Table 1. The percentage of skill-based errors involving stall/spin, airspeed, and aircraft control were greater for fatal than non-fatal accidents. In contrast, causal factors such as directional control and compensation for wind conditions were rarely associated with fatal accidents.

Such findings make sense when one considers that errors leading to a stall/spin, as well as airspeed and control of the aircraft in the air typically happen at altitude, making survival less likely. In contrast, errors controlling the aircraft on the ground (such as ground loops) and compensation for winds (typically seen during cross-wind landings), while dangerous, don’t necessarily result in fatalities.

Decision Errors. Table 2 presents the most frequently occurring decision errors. Improper in-flight planning tops the list, contributing to roughly 18% of all decision errors. The remaining decision errors, such as preflight planning/decision errors (8.94%), fuel management (8.73%), poor selection of terrain for takeoff/landing/taxi (7.85%), and go-around decisions (6.03), all occurred at approximately the same

frequencies. Combined, these five causal categories accounted for roughly half (49.89%) of all decision errors in the database. It should be noted, individual factors related to weather-related decision making did not reach the top of the list (e.g., weather evaluation, flight into adverse weather, and inadvertent VFR flight into IMC). However, when combined, they did constitute a significant portion of the factors related to decision-making (6%).

Table 2 also presents the types and frequencies of decision errors for fatal/non fatal and seminal events. As indicated, the categories in-flight planning and planning/decision making on the ground tended to be associated more often with fatal than non-fatal accidents. Whereas the categories unsuitable terrain, go around, and fuel management were associated more often with non-fatal accidents. This pattern was generally consistent for the overall data, as well as within seminal events.

Perceptual errors. A review of accident causes and factors coded as perceptual errors revealed that misjudging distance was most common, accounting for over a quarter of all perceptual errors (26.4%; see Table 3). The next highest was flare (22.5%), followed by misperceiving altitude (11.4%), misjudging clearance (7.0%) and visual/aural perception (5.1%). Together these errors accounted for nearly three quarters of all perceptual errors in the database.

The types and frequencies of perceptual errors as they occurred within fatal/non-fatal accidents are also shown in

Table 3. There was very little difference in the percentage of fatal and non-fatal accidents associated with any particular type of perceptual error. The only exception appears to be perceptual errors related to performing the flare, which in most cases is associated more with non-fatal than fatal accidents.

Violations. The *top five* violations are presented in Table 4. Analysis of the fundamental types of unsafe acts that are included within the violations categories reveals that the most common violation involved visual flight rules (VFR) flight into instrument meteorological conditions (IMC) (15.5%) and not following known procedures or directives (10.9%). The remaining top violations included operating aircraft with known deficiencies (9.9%), performing hazardous maneuvers, such as low altitude flight or buzzing (8.7%), and flight into adverse weather (8.5%). Together, these five variables accounted for over half of all violations in the database.

The types and frequencies of violations for fatal/non-fatal and seminal events are also presented in Table 4. As indicated, the categories VFR flight into IMC, hazardous maneuver, and flight into known adverse weather were much more likely to be fatal than non-fatal, both overall and for seminal events only. This pattern is consistent with the observation that accidents involving violations of the rules are, in general, more likely to be fatal.

Table 1. *Five Most Frequent Skill-based Error Categories for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	OVERALL Frequency (%)			SEMINAL Frequency (%)		
	Fatal	Non-fatal	Total	Fatal	Non-fatal	Total
Directional Control	20 (0.50)	2018 (15.2)	2038 (11.8)	9 (0.57)	1326 (17.5)	1335 (14.6)
Airspeed	713 (17.9)	1127 (8.5)	1840 (10.6)	302 (19.2)	605 (8.0)	907 (9.9)
Stall/Spin	592 (14.9)	753 (5.7)	1345 (7.8)	84 (5.3)	144 (1.9)	228 (2.5)
Aircraft Control	654 (16.5)	665 (5.0)	1319 (7.6)	311 (19.8)	429 (5.7)	740 (8.1)
Compensation for winds	23 (0.6)	1046 (6.2)	1069 (6.2)	12 (0.8)	859 (11.4)	871 (9.5)

Table 2. *Five Most Frequent Decision Error Categories for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	OVERALL Frequency (%)			SEMINAL Frequency (%)		
	Fatal	Non-fatal	Total	Fatal	Non-fatal	Total
In-flight Planning	268 (22.9)	683 (17.0)	951 (18.3)	133 (22.6)	427 (19.8)	560 (20.4)
Planning/Decision-making on the Ground	115 (9.8)	349 (8.7)	464 (8.9)	89 (15.1)	284 (13.1)	373 (13.6)
Fuel Management	40 (3.4)	413 (10.3)	453 (8.7)	20 (3.4)	252 (11.7)	272 (9.9)
Unsuitable Terrain Selection	16 (1.4)	391 (9.8)	407 (7.8)	5 (.85)	284 (13.1)	289 (10.5)
Go Around	22 (1.9)	291 (7.3)	313 (6.0)	5 (.85)	70 (3.2)	75 (2.7)

Table 3. *Five Most Frequent Perceptual Error Categories for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	OVERALL Frequency (%)			SEMINAL Frequency (%)		
	Fatal	Non-fatal	Total	Fatal	Non-fatal	Total
Distance	26 (17.8)	233 (27.7)	259 (26.4)	23 (33.8)	135 (26.5)	158 (27.4)
Flare	5 (3.4)	217 (25.8)	222 (22.5)	4 (5.9)	163 (32.0)	167 (28.9)
Altitude	22 (15.1)	91 (10.8)	113 (11.4)	9 (13.2)	51 (10.0)	60 (10.4)
Clearance	18 (12.3)	51 (6.1)	69 (7.0)	14 (20.6)	41 (8.1)	55 (9.5)
Visual/Aural Perception	15 (9.6)	36 (4.2)	50 (5.1)	3 (4.4)	5 (1.0)	8 (1.4)

Table 4. *Five Most Frequent Violations for Fatal and Non-fatal Accidents.*

ERROR CATEGORY	OVERALL Frequency (%)			SEMINAL Frequency (%)		
	Fatal	Non-fatal	Total	Fatal	Non-fatal	Total
VFR Flight into IMC	305 (25.8)	53 (4.7)	358 (15.5)	182 (30.5)	29 (5.2)	211 (25.8)
Procedures/Directives Not Followed	75 (6.3)	176 (15.6)	251 (10.9)	37 (6.2)	109 (19.6)	146 (12.7)
Operating Aircraft with Known Deficiencies	61 (5.2)	168 (14.9)	229 (9.9)	27 (4.5)	97 (17.4)	124 (10.8)
Hazardous Maneuver	154 (13.0)	47 (4.2)	201 (8.7)	83 (13.9)	24 (13.9)	107 (9.3)
Flight into Known Adverse Weather	135 (11.4)	61 (5.4)	196 (8.5)	85 (14.3)	41 (7.4)	126 (10.9)

DISCUSSION

The high level of safety currently achieved within aviation should not obscure the fact that many aviation accidents are preventable. It is important to realize that safety measures and defenses currently in place in GA may be inadequate, circumvented, or perhaps ignored, and that the intervention strategies aimed at reducing the occurrence or consequences of human error may not be as effective as possible.

The present study of GA accidents examined literally thousands of unsafe acts committed by pilots, perhaps suggesting that, correspondingly, there are literally thousands of unique ways to crash an airplane. The results of this study, however, demonstrate that accidents that may appear to be unique on their surface can be reliably grouped based upon underlying cognitive mechanisms of pilot errors. By applying HFACS, a theoretically based model of human error, we were able to highlight several human error trends and identify the categories of unsafe acts that contribute to both fatal and non-fatal GA accidents. Ideally, data such as this will result in more data-driven intervention efforts being developed and implemented.

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